

Project Title: Visual Interactive Learning of Engineering Concepts  
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## **Executive Summary**

The project developed a visual interactive learning method to help engineering student to understand basic concepts. Many engineering concepts explain the relationships between various parameters. These includes how a condition parameter affects the property parameters and how a property parameter affects the performance parameters. It is not only boring to remember those relationships in their mathematical format but more importantly difficult to map the concept to engineering practical cases. Traditionally, demonstrative experiments have been used to assist students to learn and digest the concepts. This is not only costly but frequently unable to be setup. For example, it is very difficult to use an experiment to show students that the stress has been concentrated in the cracking area in components during loading. However, if students can see the phenomena by themselves during learning and witness the correspondence of a parameter to the change of another interactively, the concept will be easier to understand and better to digest. Interactive computer vision is a method to address the problem.

The computing community in UK and the world has produced vast amount of code package and data to simulation engineering problem for research purpose. Many code packages are free to use for academic purposes. The publication of the raw data for sharing and further implementation becomes an increasing requirement by many journals. Those resources could be used in teaching to assist engineering students to achieve better understanding of the engineering problems, aware of novel solutions and get insight to the fundamental mechanisms.

The sprint of the method is to have an interactive interface so that students are able to change the parameters in whatever ways they liked and to view and analyse the change of other related parameters in a virtual three-dimensional environment. This helps student to summarize and then build up a relationship between parameters in the engineering problem. From the visual interactive learning, the fundamental concepts are formed naturally in students' mind at more enjoyable manner. We have built up three cases during the period of this scholarship project.

## **Aims and scope of your project**

- What were the main aims of the project?

The proposal seeks to develop the three-dimensional visual interactive learning software to help engineering students to understand some fundamental concepts. During years of teaching in engineering discipline we have noticed the significant difficult when students were learning and digesting those concepts. Experimental illustration helps in certain extents but often insufficient due to the restriction of dynamic property measurement. Therefore, we proposed to develop a visual interactive learning method to address these problems. The method uses a three-dimensional visual interactive software to enable students to simulate the engineering questions, to choose various parameters to affect the system, to record the evolution of properties and to compare the observation with the description in teaching materials.

- What were the more specific goals?

This proposal was to provide a proof of concepts study. We intend to identify 3 representative but correlative examples from materials modules and to develop the visual interactive learning toolkits to help students understanding those concepts. Each toolkit, after the development and

passing of our preliminary trial, will be passed to students for volunteer trial. We are aiming to promote the learning method to engineering courses such as T367 and T460 firstly. MatVisual (<http://www.matvisual.com>) software was implemented in the project.

### Activities

We developed three cases that demonstrate three different engineering concepts. The details are in the followings

#### *1. Diffusion and up-slope diffusion concept*

This case demonstrates the materials' mixing and de-mixing. The textbook normally describes the diffusion using Fick's second law. It is a second order partial differentiative equation. The analytical solution at one-dimensional case is an Error function, and in two- and three-dimensional cases not available. Students can understand the mixing from a feeling of smelling the perfume from distance and witness the mixture of coffee with milk. However, this is only half of the knowledge. Materials can also de-mixing, e.g. oil separates from water in their originally stirred mixture. Those two contradictory cases make student confusing. From this interactive software, student can understand the fundamental reason behind these phenomena and how the diffusion is affected by various parameters. For a binary fluid containing species A and B. Learners can change the interactions between species and see the evolution of materials constitution in three-dimensional space with time. Fig.1 shows a case when the interactions satisfy certain criteria, where the materials are mixed after a while. In another criteria, however, the mixed materials are separated, as is shown in Fig. 2. This enables students to understand the fundamental parameters to control materials behaviour. Furthermore, the rate of mixing and de-mixing can also be affected by other parameters such as diffusivity and liquid convection rate. Students are able to play those parameters and see how the parameters alter the materials behaviour. Fig.3 shows the examples of the effects of those parameters. In engineering, they will learn that copper-nickel alloys can mixed completely and is used for marine applications due to their excellent resistance to seawater corrosion but aluminium-lead alloys tries to de-mix which has been used for car brake pad due to the high wearability.

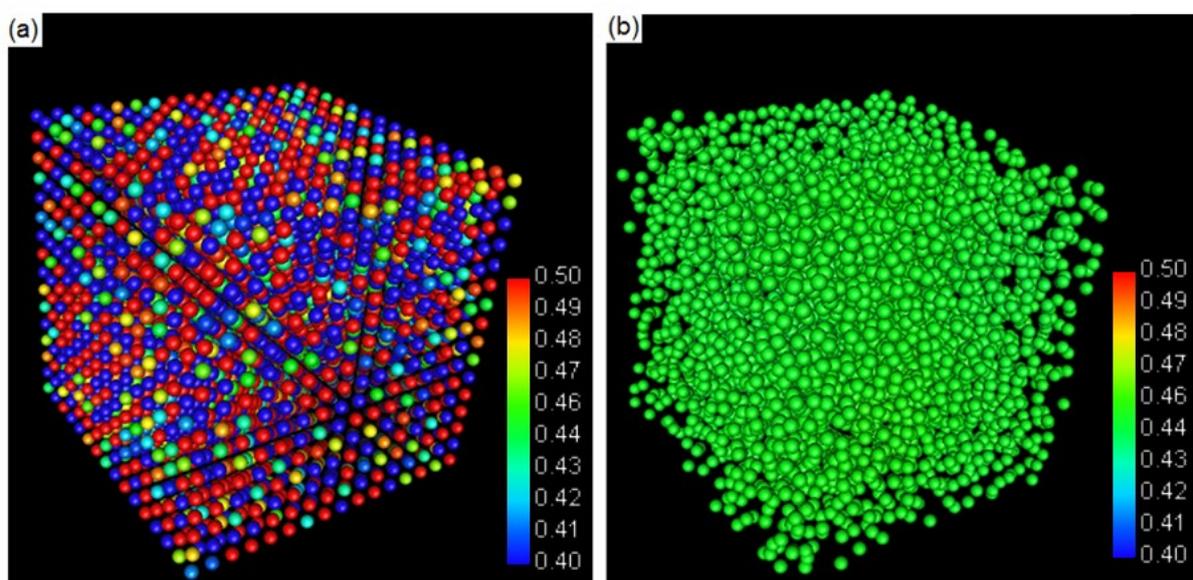


Figure 1. Configurations of mesoscopic particles at (a) 0 and (b)  $1 \times 10^5$  time steps. The colour spectrum corresponds to the solute concentration from 0.4 to 0.5.

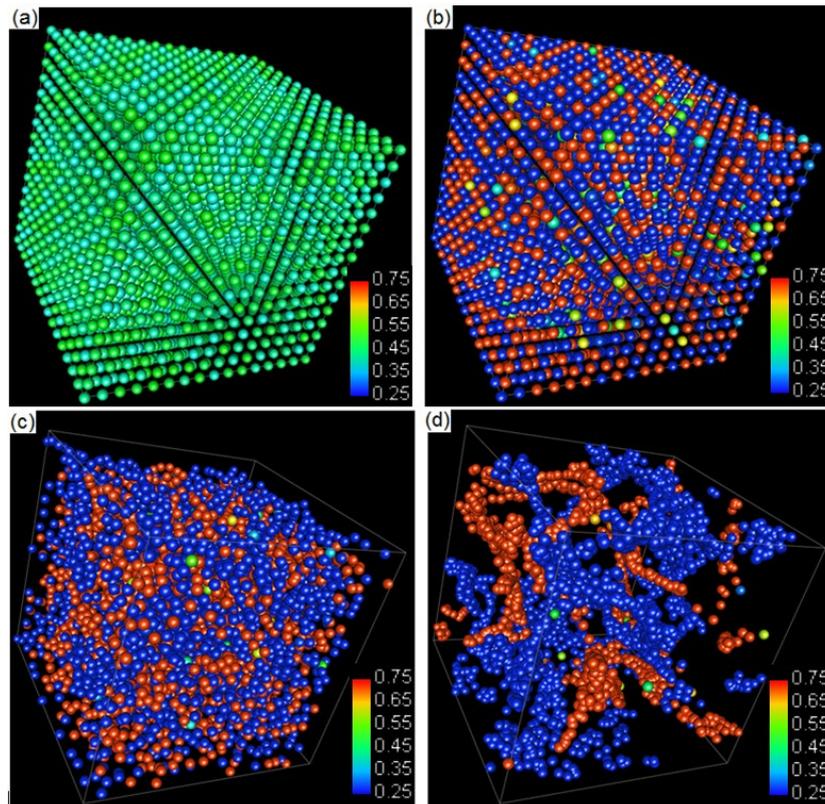


Figure 2 Particle solute distributions at 0,  $10^3$ ,  $10^4$ , and  $10^5$  time steps. The colour spectrums are from blue (0.25) to red (0.75).

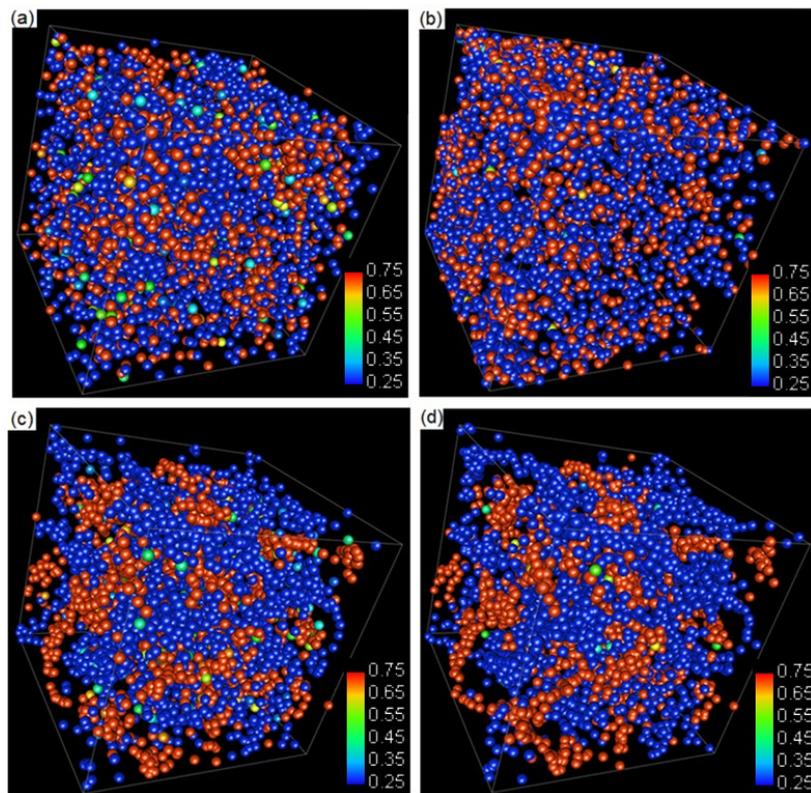


Figure 3. (a) High speed low diffusivity; (b) high speed high diffusivity; (c) low speed low diffusivity and (d) low speed high diffusivity. The spectrum is between 0.25 to 0.75.

## 2. Surface roughness and processing

Surface roughness measures surface property. It affects materials adhesion, lubrication, crack initiation, corrosion and diffraction of electromagnetic waves. Surface theory uses surface roughness to describe surface property. However, metrology uses not only the surface roughness but also surface profile to describe the surface. The case helps students to understand the definition of surface roughness, the important of the surface profile and the potential processing to improve materials surface property. Students can change any one of four parameters through an interactive interface. The combination of the parameters' values determines the surface textures. The texture is shown in three-dimensional visualization software, as is illustrated in figure 4 for some cases. The roughness of each surface texture is automatically calculated, along with the surface area. Student will find that the change of some parameters changes the surface texture and surface area drastically but not alter the surface roughness. It shows the reason why metrology use more parameters than roughness to describe the surface. Based on the interactive learning, students will get the insight on materials processing to change the surface properties.

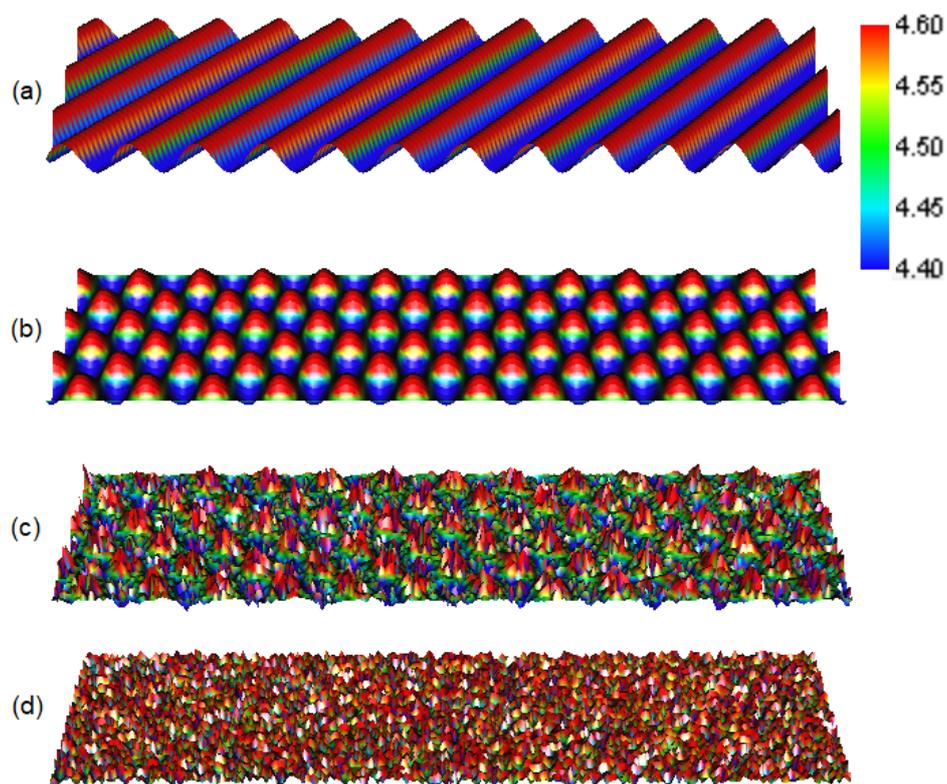


Figure 4. Surface textures generated by the various parameters. The roughness is: (a) 63.6  $\mu\text{m}$ , (b) 79.6  $\mu\text{m}$ , (c) 85.5  $\mu\text{m}$  and (d) 98.7  $\mu\text{m}$ .

## 3. Continuous casting

Each year, the world produces >1.6 billion tons of steel. Over 90% productions go through the continuous casting procedure. This case demonstrates to students the structure and functionality in a continuous casting mould during production. Through the interactive learning, students will be able to understand the fundamental principles in the continuous casting. Figure 5 shows some snapshots of the three-dimensional interactive visual analysis.

Figure 6 shows the parameters that students can adjust and the phases that student can select to view in three-dimensional visualization.

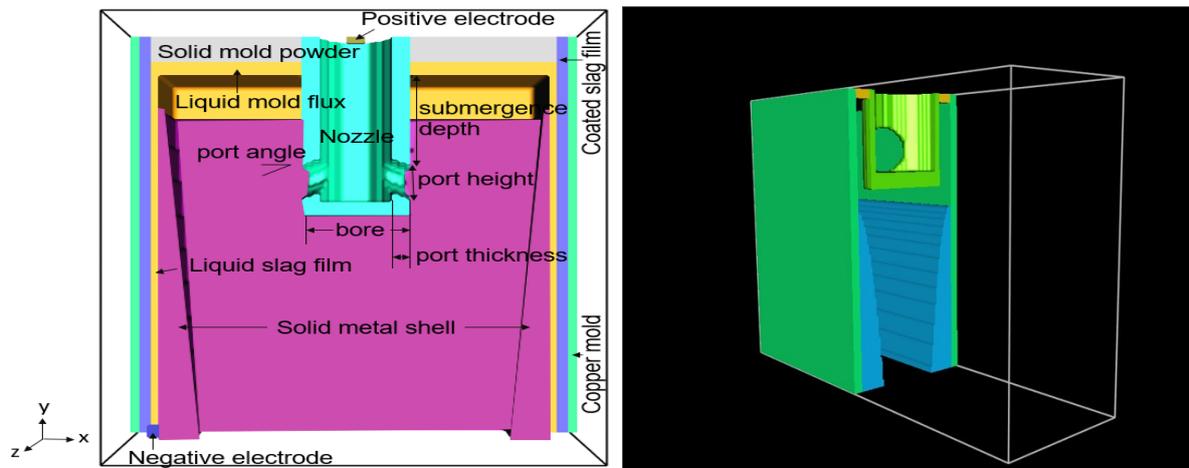


Figure 5. The internal structure of continuous casting

copper_mold_length	241
copper_mold_height	300
copper_mold_depth	121
copper_mold_thickness	6
nozzle_bore	60
port_thickness	10
port_height	26
port_angle_tan	0.577
submergence_depth	100
solid_mold_powder_thickness	20
liquid_mold_flux_thickness	10
liquid_slag_film_thickness	4
glassy_slag_film_thickness	3
crystalline_slag_film	3
steel_shell_coefficient	0.15

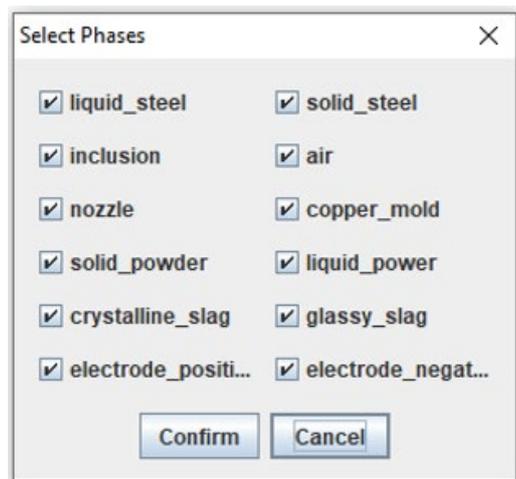


Figure 6. The adjustable parameters and the selective phases to illustrate.

## Findings

These investigated cases have led to the publication of following four journal papers

1. Z. C. Zhao, R. J. Moat, Rongshan Qin, Mesoscale modelling of miscible and immiscible multicomponent fluids. *Scientific Reports*, Vol. 9, pp 8277 (2019).
2. Rongshan Qin, Suppression of the surface roughness and fluctuation frequency by electric method, *Materials Today Communications*, Vol.28, pp.102512 (2021).
3. Rongshan Qin, Using electric field to monitor the continuous casting, *IEEE Xplore* (2021), accepted paper.
4. Rongshan Qin, Ashutosh Bhagurkar, Improving the surface properties of conductive materials by pulsating solidification, submitted paper.